Clim. Past Discuss., 4, 271–287, 2008
www.clim-past-discuss.net/4/271/2008/

Climate of the Past Discussions

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Shifts in early spring wind regime in North-East Europe (1955–2007)

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Received: 31 January 2008 – Accepted: 4 February 2008 – Published: 4 March 2008

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Published by Copernicus Publications on behalf of the European Geosciences Union.

Abstract

Changes of the winter-to-spring switch-time of the upper air flow regime at 850 and 500 hPa levels over the north-eastern Baltic Sea are analyzed based on a data set extending until 2007. The long-term variation of the air flow in early spring (March) exhibits multiple regime shifts. The shifts are extracted by means of a vector analysis of the monthly mean air flow as well as the statistical shift detection technology. In the middle of the 1960s the average air flow turned from NW (WNW) to W (WSW) at the 500 (850) hPa level. The original regime was restored in the mid-1990s. The regime shifts in the average air flow in March can be interpreted as changes in the transition time from winter to summer circulation type.

1 Introduction

There is numerous evidence indicating the gradual change of the climate of the entire Baltic Sea region such as an annual warming trend of 0.08 K/decade over 1871–2004 or an increase in precipitation over the latter part of the 20th century (BACC, 2008). Most of the relevant analysis has been concentrated on extracting linear trends in local meteorological parameters. A decrease of snow cover during the second half of the winter (Tooming and Kadaja, 2000), an increase of the amount of low clouds in March (Keevallik and Russak, 2001), warming tendencies in late winter and spring (Jaagus, 2006; Keevallik, 2003), or decrease of the duration of the ice cover (Sooäär and Jaagus, 2007), among others, have been noticed in Estonia.

Another set of evidence of climate change can be extracted from changes of air circulation patterns that are one of the key components of the local weather system and a generic indicator of climate changes and shifts. The classical examples are NAO and AO indices, frequency of circulation forms according to the Vangenheim-Girs classification, and the Northern Hemisphere teleconnection indices (Jaagus, 2006). The changes listed above frequently stem from the changes in the atmospheric circula-

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tion. In particular, the persistence of the circulation patterns is directly linked to surface air temperature anomalies (Kysely, 2007) and apparently with the occurrence of other extreme weather events.

The analysis of the changes of large-scale circulation patterns is usually made separately for the winter and summer seasons (e.g. Kysely and Huth, 2006). In the North European boreal environment these seasons exhibit completely different circulation patterns and air flow properties. For example, much of the increase of the annual wind speed over the Baltic at 850 hPa over the period of 1953–1999 (Pryor and Barthelmie, 2003) has occurred during the winter season. Also the above changes in meteorological parameters mostly characterize the late winter and spring. The changes also have nontrivial spatial patterns even in relatively small regions; for example, the changes of the wind speed at the 850 hPa level are most pronounced in the southern Baltic (Pryor and Barthelmie, 2003).

It is therefore extremely important to correctly separate the start and end of different seasons: direct calendar-based approach may easily lead to overlooking of the changes and/or to contradicting results. A primary indicator of the changes of seasons is the relevant switch of the circulation patterns. It can be identified from secondary parameters such as cloudiness, temperature etc. As these parameters frequently are strongly affected by local conditions, changes of the overall air flow serve as a more adequate pointer.

An appropriate data set for identifying the time of switch between the winter and summer circulation types is the data series of upper air winds. In the present paper we address the potential changes of the switch-time of the air flow regime over the north-eastern Baltic Sea based on a time series of upper air winds extending until 2007. The data provides novel information that could not be extracted from shorter time series. The long-term variation of the air flow does not follow simple linear trends; instead, it exhibits clearly defined regime shifts that have occurred more than once during the period in question. The shifts become evident already from a simple vector analysis of the monthly mean air flow and are clearly visible from the statistical shift detection technology of Rodionov (2004).

2 Data

We use the speed and direction of upper air winds registered at Tallinn Aerological Station (Fig. 1) since 1953. A few changes in its operation and equipment may affect the consistency of the data. The station was situated at Kose (59°28′N, 24°49′E) in 1953–1977 and was moved to Harku (59°38′N, 24°58′E, approximately 10 km to the West from its original location) in 1977. Manually operated A-22 radiosondes used in 1953–1977 were replaced by devices PK3-5 and MAP3-2 (manufactured in the former USSR) from August 1977 to May 1986 and from June 1986 to 1992, respectively. Since 1993 GPS-based DiGi Cora sondes from Vaisala are used. Soundings have been carried out four times a day in 1977–1992 and only at 00 GMT since then.

The homogeneity of the time series was examined in (Keevallik and Rajasalu, 2001; Keevallik, 2003) with the use of several tests, including the standard normal homogeneity test against data from Jokioinen Observatory (Fig. 1). No significant breaks were found and the data series may be considered as homogeneous. In order to eliminate the potential influence of several measurements a day, only midnight data (that cover the entire period 1953–2007) are considered below. As this time series has several gaps, only the months hosting at least 16 midnight soundings are taken into account.

Variations of the upper wind properties not necessarily become evident in surface wind data from inland stations. Winds over sea surface, however, are thought to well reflect the free flow properties. Unfortunately, wind properties in the vicinity of Tallinn are substantially affected by the presence of land and/or contain significant inhomogeneities (Keevallik, 2003; Soomere and Keevallik, 2003). The closest station well reflecting marine wind properties (Soomere and Keevallik, 2001, 2003) is located at the Island of Vilsandi (58°23′N, 21°49′E), a small island at the eastern border of the northern Baltic Proper. The distance between Vilsandi and Harku is approximately 200 km, i.e., considerably less than the typical size of free-flow circulation cells in this area.

Although wind measurements were started at Vilsandi as early as in 1865, changes in measurement equipment and routine have affected the data homogeneity. It is generally accepted that data before 1966 should not be used together with the later data for trend analysis (Keevallik et al., 2007). Thus, from eight routine recordings a day of wind data at Vilsandi, the midnight (00 GMT) data from 1966–2005 were selected to compare the results of sampling of the upper air flow with simultaneous surface wind measurements.

3 Average air flow in the free atmosphere

For our purposes, the most convenient property is the average air flow during intervals considerably larger than the duration of influence of a particular circulation cell at the measurement site. This property combines wind speed and direction, and is equivalent to a combination of the analysis of any two wind velocity components. Below we use the classical wind velocity components (u, v), calculated from traditionally measured wind speed and direction. Here u is the zonal wind component, positive to the East, and v is the meridional wind component, positive to the North. The results of their analysis will be compared with the long-term changes in wind speed, which is another variable that is frequently looked at in the analysis of the average air flow and that may also indicate changes in large-scale circulation.

The annual course of the upper air flow above Estonia is typical for the north-eastern Europe up to the polar front. Wind speed is relatively large during the autumn season (October–January), decreases considerably during the late winter and spring, and has a clearly defined minimum in midsummer (Fig. 2). A large part of this variation is caused by changes in the intensity of the zonal flow component. The properties of local weather, however, reveal relatively weak dependence on the wind speed and are much more strongly determined by the direction of the flow. Autumn and winter weather is attributed to a northerly air flow whereas spring and summer conditions are brought to Estonia by a southerly air flow. The switching between the two types of flow is quite abrupt in March–April and smoother at the end of August (Fig. 2). The potential shifts of this time are decisive for many above-discussed parameters such as the duration of snow cover or the length of the ice season.

While the timing of the autumn switch exhibits no significant trends within the latter half-century, several intriguing changes in free flow patterns during the spring switch were recently established. Significant positive trends in wind meridional component were detected in March for the period of 1955–1995 (Keevallik, 2003). The increase of this component was 0.10 (0.16) m/s per year at the 850 (500) hPa level. Statistically significant trends of increasing velocity existed for the zonal component at 850 hPa: 0.10 m/s per year in February and 0.08 m/s per year in March (Fig. 3). There were no changes in the temporal course of meridional wind component in February.

Extension of the time series until 2007 reveals that the quantities in question generally possess no unambiguous trends. Instead, certain more complex features of decadal variations become evident.

During 1955–2007 the zonal wind component at the 850 hPa level shows still significant (level 0.1) positive trend. Its formal slope is 0.051 m/s per year in February, i.e., about a half of that during 1955–1995. Figure 3, however, reveals that extremely large variations of the zonal wind component occurred in February compared to its monthly mean (about 5 (7) m/s at the 850 (500) hPa level). A total collapse of the zonal flow occurred in the mid-1980s and during a few years even easterly flow predominates. The zonal flow was restored at a much more intense level at the end of the 1980s, with its typical monthly mean values about twice as large as in the 1960s and the 1970s. At the turn of the century, another drastic reduction of the average zonal flow occurred.

Such sawtooth-like behavior of the zonal wind component suggests that certain regime switches have occurred. Since there were no simultaneous changes of the meridional wind component, the switches apparently led to certain variations of the overall (incl. surface) wind speed that can be first detected from marine observations. The described features qualitatively coincide with the course of annual mean wave ac-

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tivity in the northern Baltic Sea. The annual mean wave height was relatively low in the 1980s, increased considerably from the end of the 1980s, achieved the largest level of the latter 50 years in the mid-1990, and decreased by a factor of three by the year 2005 (Broman et al., 2006; Soomere and Zaitseva, 2007).

For the newly available data during 1955–2007, neither zonal nor meridional wind component shows significant trend in March (Fig. 3). The behavior of the meridional wind component in March, however, exhibits extremely interesting course offering several interpretations. One may first notice that the increasing trend (corresponding to gradual change of the direction of the mean air flow from NW to W) was replaced by a decreasing trend with roughly the same slope in the mid-1980s. The overall course may also be interpreted as an evidence of a long-term quasi-periodical behavior, with the period larger than the duration of the time series.

The above discussion of the character of the zonal flow in February leads to a perception that regime shifts in the wind system may have taken place. The existence of such shifts becomes qualitatively evident from the analysis of the decadal average air flow in March. The years when the regime was changed can be roughly established from a simple vector representation of the air flow. While the mean air flow on the 500 hPa level was from NW in 1955–1966, it was mostly from W over about three decades and reversed back to NW just before the turn of the millennium (Fig. 4). Although the time instants of changes in Fig. 4 have been selected visually, the overall behavior of the air flow suggests that major shifts have occurred in the mid-1960s and in the mid-1990s.

An equivalent shift from the predominating WNW air flow at the 850 hPa level to a WSW flow took place in the mid-1960s. The reverse of the flow to the original direction occurred in the mid-1990s (Fig. 5). The magnitude of the shift in the direction is approximately the same at both levels. This feature suggests that a turn of the free flow has occurred at all heights. Although such turns not necessarily become evident at surface level, the average surface-level air flow at midnight at Vilsandi reveals the influence of the switch in the mid-1990s. The monthly mean surface air flow headed to the

NNE during 1976–1995 (Fig. 5), but turned abruptly to almost E in the mid-1990s and decreased to some extent in speed. Unfortunately, such a comparison is not available for the Vilsandi data for the years before 1966.

4 Regime shifts

The above suggests that at least two substantial shifts of the meridional component of the upper air flow above Estonia have occurred since the 1950s. A more exact identification of the time instant of the shifts is possible by means of technique elaborated by Rodionov (2004; Rodionov and Overland, 2005). The timings of regime shifts (Table 1) are found using cut-off length of 10 years and Huber's weight parameter of 2 (i.e., all wind component values that are less than two standard deviations have equal weights). This technology reveals that at least two regime shifts have taken place in the average air flow on the 500 hPa level in March: one in the mid-1960s and another in the mid-1990s. Additionally, the method signals the possibility of a future regime shift. Also, regime shifts in the zonal flow in February are evident in the mid-1980s (when its intensity abruptly increases) and at the beginning of the 2000s when the average zonal flow decreases again. No clear shifts in the character of the air flow occurred during other months. The described shifts are less clearly visible in surface data: only an abrupt increase of the zonal flow in February and March occurred at the end of the 1980s.

5 Conclusions and discussion

The annual course of the upper air flow over Estonia has two typical regimes: a relatively intense north-westerly flow during the autumn and winter season (September–February) and a less intense south-westerly flow during the spring and summer season (April–August). The flow transition is quite abrupt at the beginning of the summer season, but fairly smooth at its end (Fig. 2).

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The key outcome of the above analysis is that the long-term variation of the transition time hosts neither simple linear trend nor periodic behavior. It exhibits certain clearly defined multiple regime shifts. The largest changes have occurred in March. In the middle of the 1960s the average air flow in March turned from NW to W at the 500 hPa level. The original regime was restored in the mid-1990s. Analogous changes (the turn of the air flow from WNW to WSW and back) occurred also in the air flow at the 850 hPa level and at the surface.

The regime shifts in the average air flow in March can be interpreted as changes in the transition time from winter to summer circulation type. March was characterized by winter circulation in the 1950s. During about 30 years from the mid-1960s the summer circulation started several weeks earlier. From the mid-1990s the start of the summer circulation was again postponed to April as in the 1950s. Equivalently, it may be hypothesized that the circulation system above Estonia moved between different quasistationary states whereas the one that dominated approximately in 1966–1996 corresponded to clearly shorter winters. The large jump of the transition time and the persistence of all the regimes suggest that the regime switches mimic changing properties of certain large-scale processes with a small number of degrees of freedom such as the location of the polar front and/or the nodes of the planetary wave system.

Such regime shifts may be reflected in associated climatological parameters such as variations of level of large lakes in the northern Europe (Järvet, 2004). They are apparently accompanied by changes in surface temperature, precipitation and low cloudiness. The analysis of such changes is currently in progress.

The identified regime changes are consistent with the sharp increase of the persistence of circulation patterns in all seasons from the 1970s to the late 1980s (Kysely and Domonkos, 2006). Our analysis, however, sheds more light to the "outlier" period of the very end of the 20th century. It is highly probable that the air flow in spring has simply reversed to the pattern that dominated in the middle of the 20th century. One, however, cannot judge whether this regime is equivalent to the one in the 1950s. The reverse combined with a considerable increase of the persistence of circulation types

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may be one of the reasons of the increase of climatic extremes, in particular, of wind-induced wave and storm surge extremes in the Baltic Sea basin (Suursaar et al., 2006; Soomere et al., 2008) that were seldom evident before the 1960s but are frequently observed in Europe during recent years (Kysely and Huth, 2006).

Acknowledgements. The 5 authors are grateful to K. Loitjärv for digitizing aerological data for the period of 1999–2007 from the archive of the Estonian Meteorological and Hydrological Institute. The research was supported by Estonian Science Foundation, Grants 5762 and 7413.

References

The BACC Author Team: Assessment of Climate Change for the Baltic Sea Basin. Springer, 2008.

Broman, B., Hammarklint, T., Rannat, K., Soomere, T., and Valdmann, A.: Trends and extremes of wave fields in the north-eastern part of the Baltic Proper, Oceanologia, 48(S), 165–184, 2006.

Jaagus, J.: Climatic changes in Estonia during the second half of the 20th century in relationship with changes in large-scale atmospheric circulation, Theor. Appl. Climatol., 83, 77–88, 2006.

Järvet, A.: Influence of hydrological factors and human impact on the ecological state of shallow Lake Võrtsjärv in Estonia, Dissertationes Geographicae Universitatis Tartuensis, Tartu, Estonia, 2004.

Keevallik, S. and Russak, V.: Changes in the amount of low clouds in Estonia (1955–1995), Int. J. Climatol., 21, 389–397, 2001.

Keevallik, S. and Rajasalu, R.: Winds on the 500 hPa isobaric level over Estonia (1953–1998), Phys. Chem. Earth PTB, 26, 425–429, 2001.

Keevallik, S.: Changes in spring weather conditions and atmospheric circulation in Estonia (1955–1995), Int. J. Climatol., 23, 263–270, 2003.

Keevallik, S., Soomere, T., Pärg, R., and Žukova, V.: Outlook for wind measurement at Estonian automatic weather stations, Proc. Estonian Acad. Sci. Engineering, 13, 234–251, 2007.

Kysely, J.: Implications of enhanced persistence of atmospheric circulation for the occurrence and severity of temperature extremes, Int. J. Climatol., 27, 689–695, 2007.
Kysely, J., and Huth, R.: Changes in atmospheric circulation over Europe detected by objective and subjective methods, Theor. Appl. Climatol., 85, 19–36, 2006.
Kysely, J., and Domonkos, P.: Recent increase in persistence of atmospheric circulation over Europe: Comparison with long-term variations since 1881, Int. J. Climatol., 26, 461–483, 2006.
Pryor, S. C. and Barthelmie, R. J.: Long-term trends in near-surface flow over the Baltic, Int. J. Climatol., 23, 271–289, 2003.
Rodionov, S. N.: A sequential algorithm for testing climate regime shifts, Geophys. Res. Lett., 31, L09204, doi: 10.1029/2004GL019448, 2004.
Rodionov, S. and Overland, J. E.: Application of a sequential regime shift detection method to the Bering Sea ecosystem, ICES J. Mar. Sci., 62, 328–332, 2005.
Soomere, T. and Keevallik, S.: Anisotropy of moderate and strong winds in the Baltic Proper, Proc. Estonian Acad. Sci. Engineering, 7, 35–49, 2001.
Soomere, T. and Zaitseva, I.: Estimates of wave climate in the northern Baltic Proper derived from visual wave observations at Vilsandi, Proc. Estonian Acad. Sci. Engineering, 13, 48–64, 2007.
Soomere, T., Behrens, A., Tuomi, L., and Nielsen, J. W.: Wave conditions in the Baltic Proper and in the Gulf of Finland during windstorm Gudrun, Natural Hazards and Earth System Sciences, 8, 37–46, 2008.
Sooäär J. and Jaagus, J.: Long-term variability and changes in the sea ice regime in the Baltic Sea near the Estonian coast, Proc. Estonian Acad. Sci. Engineering, 13, 189–200, 2007.
Suursaar Ü., Kullas, T., Otsmann, M, Saaremäe, I., Kuik, J., and Merilain, M.: Hurricane Gudrun and modelling its hydrodynamic consequences in the Estonian coastal waters, Boreal Environ. Res., 11, 143–159, 2006.
Tooming, H. and Kadaja, J.: Snow cover and surface albedo in Estonia, Meteorol. Z., N.F. 9, 97–102, 2000.

Table 1. Timings of regime shifts in wind components and weighed averages of the regimes.

Period	Zonal component, m/s	Meridional component, m/s
a) 500 hPa, March		
1955–1964	7.03	–5.43
1965–1996	7.03	0.05
1997–2005	7.03	–6.20
2006–2007	7.03	–0.66
b) 850 hPa, March		
1955–1964	1.84	–1.19
1965–1966	4.47	–1.19
1967–1996	4.47	1.83
1997–2006	4.47	–1.92
c) 500 hPa, February		
1955–1986	6.02	–3.38
1987–2002	12.14	–3.38
2003–2005	3.62	–3.38
2006–2007	3.62	–8.24

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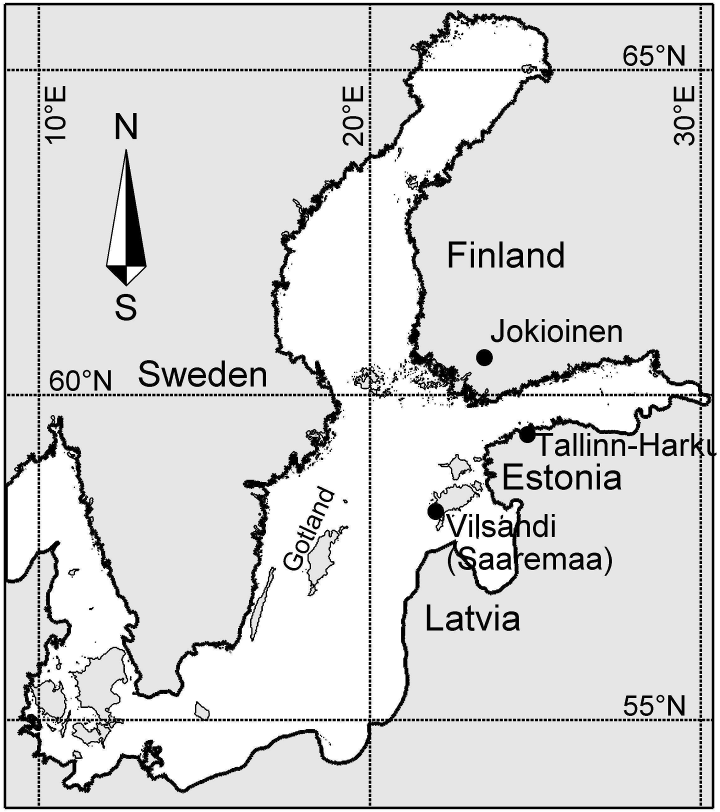

Fig. 1. Location scheme of the Baltic Sea, Tallinn-Harku Aerological Station, Jokioinen Observatory, and the Island of Vilsandi.

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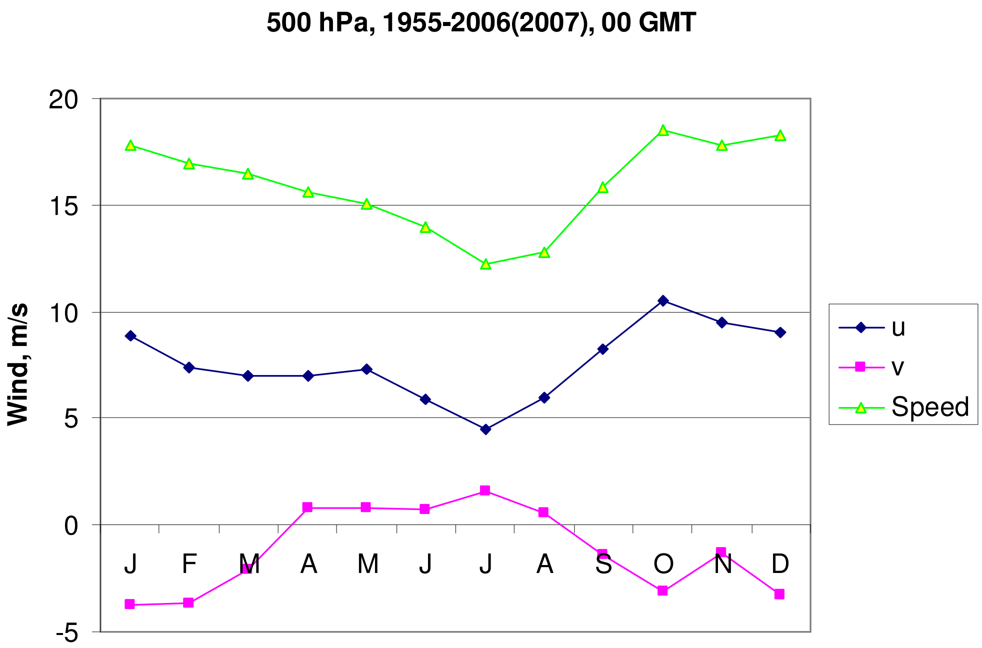

Fig. 2. Annual changes in monthly average wind speed, zonal (u) and meridional (v) wind velocity components on the 500 hPa level.

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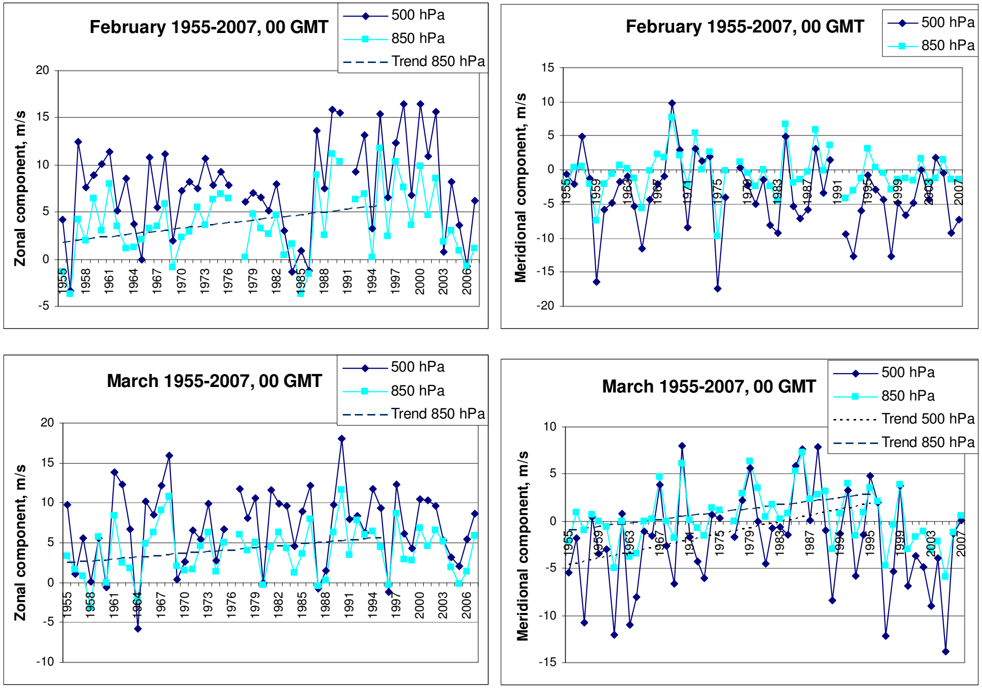

Fig. 3. Upper air wind components at two isobaric levels (500 and 850 hPa) over Estonia in February and March in 1955–2007. Trends (significant at least at the 0.1 level) established by Keevallik (2003) are shown by dashed lines extending over 1955–1995.

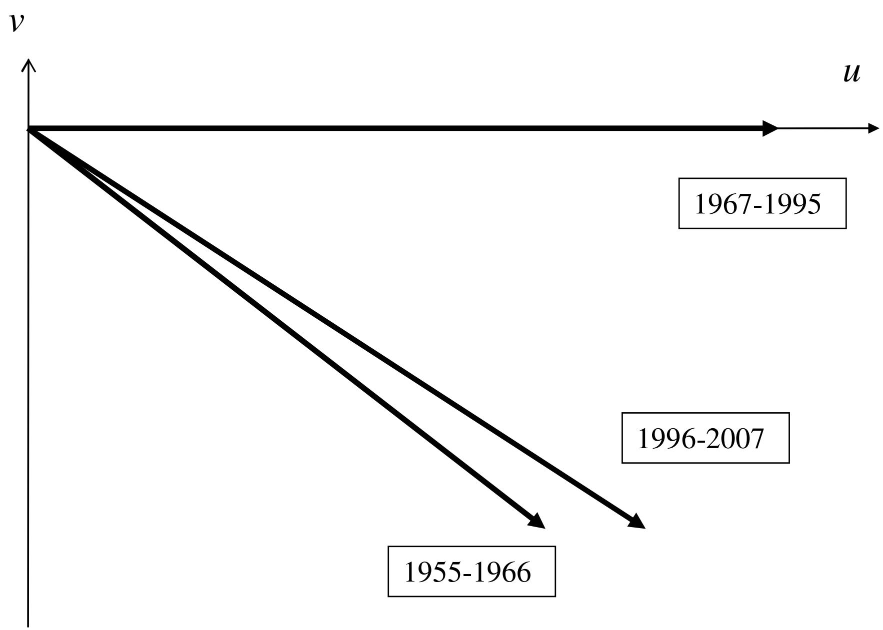

Fig. 4. Monthly average air flow at the 500 hPa level in March during different decades. The scaling of the *u*- and *v*-axes is equal.

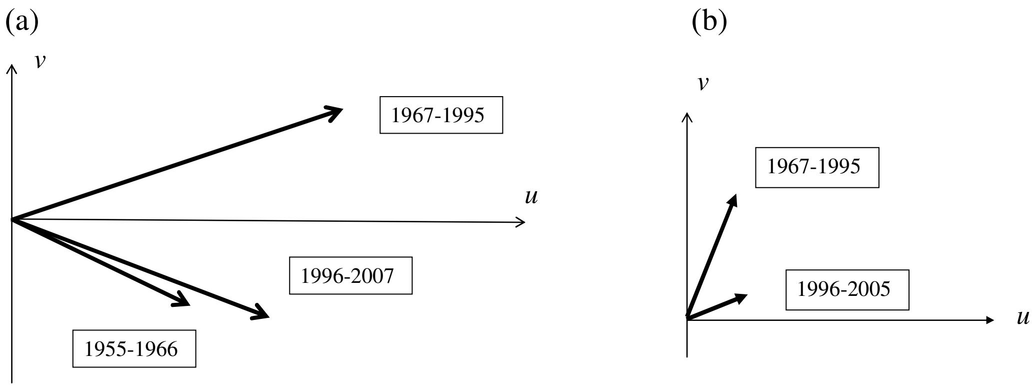

Fig. 5. Monthly average air flow at the 850 hPa level **(a)** and at the surface **(b)** in March during different decades. The scaling of the *u*- and *v*-axes is equal.

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